Thorax 1985;**40**:132–137

Longitudinal decline in FEV_1 in United States coalminers

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ABSTRACT Changes in ventilatory funtion measurements of United States miners who had participated in two surveys held nine years apart were analysed in relation to smoking habits, dust exposure, and other factors. The results showed trends similar to those reported among British miners. Loss of FEV_1 over time and found to be related to smoking (0·1 litre excess decline in current smokers compared with those who had never smoked over 11 years) and to occupational exposure (0·036–0·084 litres over 11 years, depending on the index used). The results offer confirmation of the relationship between work in coal mines and loss in ventilatory function observed in British miners, and also seen in cross sectional studies.

The National Coal Study is a longitudinal investigation of lung disease in United States underground coalminers and its association with dust exposure. Begun in 1969 with surveys at 31 nationally distributed mines, the National Coal Study has now completed two further surveys and has studied over 1400 miners for about nine years. In each of these surveys information on ventilatory function, chest symptoms, and working and smoking history was elicited. In addition, dust exposure data for these miners were obtained from the Mine Safety and Health Administration. These data have been used to examine the longitudinal change in FEV_1 over the nine year period, and its relationship to job and dust exposure. This is believed to be the first report on long term changes in ventilatory function in US miners.

The form of the National Coal Study closely resembles that of another large study of coal miners—the Pneumoconiosis Field Research of the National Coal Board in Britain. Both require the repeated examination of miners over the long term and use somewhat similar methods and techniques.

Results on longitudinal ventilatory function change in the British Study have recently been published by Love and Miller,[1] who reported changes in FEV_1 over an 11 year period. They showed correlations between decrements in FEV_1 and dust exposure after allowing for age, height, smoking, and differences between mines. It is of interest to determine whether these findings in British miners are also relevant to US miners. Our analysis has been presented on similar lines to that of Love and Miller to facilitate comparison.

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Accepted 12 September 1984

Methods

The data considered here was drawn from medical surveys taken initially at 31 nationally distributed mines from 1969 to 1971, and again from 1977 to 1981. During the period between the two surveys some mines closed, while for others too few miners attended both surveys to warrant the inclusion of those mines in the analysis. As a result, data from 24 mines were eventually available for analysis.

Participation in the first survey was good at around 95%, while that for the latter examination was poor at around 60%. This caused difficulties in analysis, which are dealt with later. Of the 9078 miners in the first round, 1470 were common to both surveys. Rejection of observations for reasons explained later reduced this number.

MEDICAL SURVEY MEASUREMENTS

Methods were similar in the two surveys. In general, the examination consisted of standard posteroanterior and lateral chest radiographs; administration of a standardised questionnaire on chest symptoms, smoking history, and work history similar to that of the Medical Research Council, and simple spirometric measurements. In the first survey the final FEV_1 recorded was the largest value of up to five exhalations (including at least two practice blows). In the later survey up to 10 blows were permitted, but for the present analysis only the first five blows have been considered for consistency with the first survey. The same type of spirometer was used at all examinations (Ohio rolling seal type), although the technicians were different. A miner whose smoking classification was the same at the initial and final surveys was defined as a non-smoker, ex-smoker, or current smoker. Those giving inconsistent replies, those taking up or stopping smoking in the interim, and those with missing information (three subjects) were classified as intermittent smokers. The number of pack years between surveys was calculated for current smokers by multiplying the interval by the number of cigarettes per day/20. For non-smokers and ex-smokers pack years were therefore zero, while for intermittent smokers the duration of smoking was taken (when valid or available) from information given by the miner on the questionnaire.

DUST MEASUREMENTS

The National Coal Study does not require routine measurement of dust concentrations for the purpose of estimating individual exposure. Instead recourse was made to compliance data collected by the Mining Safety and Health Administration (MSHA) for the purpose of dust control.[2] The rationale for the collection of dust samples in the MSHA compliance scheme differs from that which would be appropriate for epidemiological investigation: basically, the compliance scheme concentrates sampling effort on the miners expected to experience the greatest concentrations—the high risk workers. Other miners are sampled at a lower frequency. All samples were taken for respirable particulate and were converted to MRE (Mining Research Establishment) equivalent concentrations.[3] Dust data were available for the years 1970–9. Each record on the dust tapes supplied by MSHA contained information on mine, job, miner's social security number, date, and concentration among other data. Records on these tapes were linked to the medical information by means of the social security number, and then averaged by a two stage process. The data for each miner were first averaged every two months for each individual; these means were then themselves averaged. This approach was pursued because of the suspicion that the increased frequency of sampling which takes place when a coal face (section) is "out of compliance" (excessively dusty) could have biased the simple averages upwards. A two month period was chosen as the compliance scheme is organised around a two monthly programme. The number of samples averaged for each subject ranged from one to 397.

GROUPS STUDIED

One thousand four hundred and seventy miners attended both of the surveys considered here. As explained later, analysis was restricted to those aged 20–49 years; there were 1161 miners in this group. Omission of data from three mines at which the number of "survivors" was each less than 10 and exclusion of observations with missing ventilatory function data further reduced this number to 1072. This group was used in the initial analysis. Dust data for 957 of the 1072 were available; this subset was used in analysis of the association between ventilatory function decrements and dust concentration.

METHODS OF ANALYSIS

In order to ensure comparability with the methods of Love and Miller[1] the following procedure was followed. Simple decrements in FEV_1 were obtained by subtraction of the FEV_1 obtained at the later survey from the initial value. These were then standardised to an 11 year loss in FEV_1 by application of the formula

((First FEV_1 − Last FEV_1) $\times$11)/(years between surveys).

The relationships between adjusted 11 year decline in FEV_1 and potential causative and confounding variables were explored by multiple regression analysis. With adjusted 11 year decline used as a response variable, models were fitted which included combinations of age, height, smoking indicators, mine effects, and indices of dust exposure as predictor variables. Both smoking status and pack years were used to measure smoking (though not in the same model), while exposure indices included years underground before the initial survey, years worked at the face before the first survey, years worked at the face and underground between the two surveys, and average dust concentration between the surveys derived as described earlier.

Each of the models fitted included terms for age, height, mine effects, and one of the two smoking indices. (The term mine effects denotes systematic deviations in mean FEV_1 level from mine to mine which cannot be explained by corresponding variations in age, height, smoking, dust exposure, or any of the variables commonly associated with ventilatory function.) Four models were fitted which included each of the four exposure indices described above. Dust concentration was included as it is the most appropriate measure of exposure. It is, however, somewhat unreliable, as it was in many cases based on few samples. For this reason the two indirect indices of exposure, years at the face, and years underground were also used. Prior work underground was included for comparison with the results of Love and Miller.[1] Additional models were fitted which included both prior and concurrent exposure and other combinations of smoking and indices of exposure.

Results

EXPLORATION OF BIAS

Results from longitudinal studies of workers may be biased if there is a systematic exodus of certain types of workers between the surveys. This problem is further compounded if, as in this study, participation is poor. For this reason the data have been examined to see whether there is a problem of bias, and whether that problem can be alleviated or circumvented.

Data for all miners who attended the first survey were separated into those from subjects who also attended the later survey (stayers), and those from subjects who did not (leavers). It was immediately apparent that the leavers differed systematically from the stayers. Those who left were older and showed more evidence of ill health such as greater frequency of bronchitis related symptoms, lower ventilatory function, and more pneumoconiosis. The leavers also had longer employment in mining and had smoked more cigarettes.

Since much of the difference between the two groups could have been age related, the data were tabulated by age groups. This showed that age was indeed a critical factor. By controlling the age range, however, the differences between the two groups could be virtually eliminated. Table 1 shows the summarised data for the two groups for the age range 20–49 years, the range used for further analysis in this report. It is apparent that there exist only minor differences between the two groups, and thus extrapolation to miners other than those in the stayers group on this study may be valid. (The data for the 1072 miners studied here are virtually the same as those for the 1161, so that the same conclusions apply).

Table 1 *Comparison between selected variables for miners (aged 20–49 years) attending both surveys and those attending only the first: Data at first examination*

	Subjects attending survey 1 only	*Subjects attending both surveys*
Number of miners	4139	1161
Marital status (% married)	92	94
Race (% white)	97	94
Mean age (years)	37	38
% smokers	59	55
Mean pack years*	17	17
Mean years underground	11	11
Mean FEV_1 (l)	3·8	3·8
Mean FVC (l)	5·0	5·1
% reporting persistent cough	26	24
% reporting persistent phlegm	28	28
% reporting breathlessness	14	10
% ever had bronchitis	9	7
% with coalworkers' pneumoconiosis	19	22

*Mean for smokers and ex-smokers only.

Table 2 *Characteristics of the study population of 1072 men*

Variable	*Mean (SD)*
Age (years)*	44 (9)
Height (cm)	176 (7)
FEV_1 (l)*	3·61 (0·7)
Smoking status:	
Non-smokers (n = 211)	
Ex-smokers (n = 199)	
Intermittent smokers (n = 231)	
Current smokers (n = 431)	
Duration of work:	
Years underground before first study	11 (9)
Years underground between surveys†	9 (4)
Years at face between surveys†	3 (4)
Dust concentration between surveys (mg/m^3)	1·2 (0·8)

*Mid point of adjusted 11 year period.
†Adjusted to 11 year period.

ANALYSIS OF LONGITUDINAL CHANGES

Some statistics derived from the 1072 miners are shown in table 2. The mean age at the mid point of the study period was 44 years, and the subjects had spent an average of 11 years underground before the first survey. On average, close to 80% of the time between surveys was spent underground, with a mean of 30% at the face. The mean dust concentration for 957 subjects, as obtained from MSHA records, was 1·2 mg/m^3. Forty per cent of the group admitted to being current smokers at both examinations.

The 11 year adjusted decrements in FEV_1 are shown in table 3 for the 1072 miners. Decline in FEV_1 clearly increased with age and varied with smoking habit. The decrements were greater, both in absolute and in relative terms, in the older than in the younger age groups. Among the smoking groups current smokers showed the greatest decline, and non-smokers and ex-smokers the least. The data also show that FEV_1 level was lower, a finding noted by others.[1 4]

Regression models were fitted to investigate the relationship between FEV_1 changes and possible causative factors. The four models described here in detail contained terms for age, height, smoking status, mine effects, and one of each of four exposure indices: intersurvey dust concentration, intersurvey (or concurrent) years at the face, intersurvey

Table 3 *Age and smoking specific adjusted FEV_1 changes*

	Age group (y) ≤39	40–49	≥50	All
Non-smokers				
ΔFEV_1 (l)*	0·39*	0·46	0·49	0·44
Mean FEV_1 (l)†	4·21	3·63	3·50	3·81
Intersurvey pack years	0	0	0	0
(No of miners)	(80)	(62)	(69)	(211)
Ex-smokers				
ΔFEV_1 (l)*	0·32	0·42	0·50	0·44
Mean FEV_1 (l)†	4·05	3·65	3·27	3·56
Intersurvey pack years	0	0	0	0
(No of miners)	(39)	(72)	(88)	(199)
Intermittent smokers‡				
ΔFEV_1 (l)*	0·35	0·46	0·60	0·46
Mean FEV_1 (l)†	4·14	3·39	3·15	3·62
Intersurvey pack years	4·2	4·4	2·2	3·8
(No of miners)	(92)	(76)	(63)	(231)
Current smokers				
ΔFEV_1 (l)*	0·45	0·54	0·64	0·52
Mean FEV_1 (l)†	3·92	3·67	3·08	3·54
Intersurvey pack years	7·7	8·3	7·5	7·9
(No of miners)	(185)	(146)	(100)	(431)
All miners				
ΔFEV_1 (l)*	0·40	0·48	0·56	0·48
Mean FEV_1 (l)†	4·04	3·47	3·24	3·61
Intersurvey pack years	4·6	4·3	2·8	4·0
(No of miners)	(396)	(356)	(320)	(1072)

*11 year adjusted decline in FEV_1.
†Mean FEV_1 adjusted to mid point of 11 year period.
‡Information on smoking habits for some of the intermittent smokers was contradictory. In these cases the data were omitted from the mean given for this group.

years underground, and years underground before the initial survey. (The correlations between these four indices were in general not very strong: prior and concurrent underground tenure showed the greatest correlation (0·63); this reflects the tendency for miners to remain in the same jobs. The next largest correlation was between concurrent facework and concurrent underground work (0·25).)

Table 4 shows the coefficients obtained for each of the models. In all cases age, height, smoking status, and mine effects showed statistically significantly associations with decline in FEV_1 ($p < 01$). Increased age and height were associated

Table 4 *Regression coefficients with four different models on 11 year adjusted FEV_1 decline*

	Model* I	II	III	IV
Intercept	−1·22	−1·27	−1·31	−1·31
Age (years)	0·011	0·011	0·011	0·009
(p < 0·001 all models)				
Height (cm)				
(p < 0·001 all models)	0·007	0·007	0·007	0·007
Smoking status (relative to non-smokers)				
(p < 0·001 all models)				
Ex-smokers	−0·027	−0·027	−0·045	−0·028
Intermittent smokers	0·013	0·013	0·019	0·012
Current smokers	0·095	0·096	0·093	0·096
Mine effects† (p < 0·001 all models)				
Intersurvey underground work (y)	0·0034 (p = 0·29)			
Intersurvey at face (y)		0·0073 (p = 0·01)		
Intersurvey concentration (mg/m³)			0·028 (p = 0·12)	
Underground work before initial survey (y)				0·0024 (p = 0·15)
Residual SD	0·39	0·40	0·40	0·39

*Model I—using intersurvey work undergound; model II—using intersurvey work at face; model III—using intersurvey dust concentration; model IV—using prior tenure underground.
†Mine effects: Results from 24 mines were included in this analysis. The large number of coefficients precludes their inclusion here. A difference of over 0·5 litre was seen between the mine with the greatest decline and that with the least.

with greater declines while current smokers showed greater declines than non-smokers. Intermittent smokers appeared to have declined at a rate between that of current smokers and non-smokers—though, surprisingly, ex-smokers showed the lowest declines.

The number of years spent between surveys in facework was significantly associated with greater reductions in FEV_1 ($p < 0{\cdot}05$); this trend was reflected in each of the other exposure coefficients, although none achieved conventional levels of significance.

The equations shown in table 4 have been used to obtain predicted declines for various levels of exposure to dust and smoking. For the two equations using intersurvey tenure the levels of interest were both set at 0 and 11 years of work underground and at the face respectively. For the dust concentration model, values were set at 0 and 2 mg/m^3 (the current US dust standard), while zero and 35 years underground were used for model IV (for comparison with Love and Miller). Comparison was made with the difference between the effects observed for smokers and those who had never smoked.

All four models indicated that smoking was associated with an average excess reduction in FEV_1 over 11 years of close to 0·10 l. In contrast, the effect of work in coalmining or dust exposure was variously estimated at levels from 0·036 to 0·084 l. The value obtained from model II, the model in which the coefficient representing exposure showed statistical significance, was 0·080 l. The 95% confidence limits for this estimate are 0·018 and 0·142 l. Computation of the ratios of the predicted effects of smoking to dust exposure resulted in values varying from 1·1 to 2·6, with an average close to 1·5. Use of pack years instead of smoking status in models I and II (detailed results not given here) led to smoking: exposure index ratios of 2·2 and 1·2 respectively.

Discussion

Comparison of the results reported here has been made with those from the British work described recently by Love and Miller.[1] Both investigations consisted of a longitudinal study of working coalminers over roughly the same period, and used similar techniques and methods. Differences between the two studies lay largely in the dust exposure information available, in minor questions of definition such as the smoking classification, in the inclusion of slightly younger miners in the present study, and in the use of maximum rather than mean FEV_1 values.

In general the US miners were slightly younger and somewhat taller than their British counterparts. Although smokers predominated among both cohorts, the general distributions of smoking status were different, the US miners showing a more even spread over the four smoking groups considered. Mean FEV_1 levels were greater in all groups in the present study. This difference is probably due to two factors: the greater height of the US miners and the use of maximum rather than mean FEV_1 values. Examination of the effect of the latter, on the basis of data from the second survey, indicated that the maximum of five FEV_1 determinations was about 0·2 l greater than the mean of five. The correlation between the mean and the maximum was 0·96. Comparison of dust data is difficult because of the different indices used, but it is reasonable to assume that the relevant levels in US mines were lower since over the study periods the legal dust standards were generally lower in the United States.

There is good agreement between the two studies in terms of general decline in FEV_1 standardized to 11 years. Comparison of age specific FEV_1 changes (table 2 of Love and Miller[1] and table 3 of this paper) showed mean declines of 0·45 l for the under 39 year group (actually 30–39 years) among the British miners and of 0·40 l for US miners. Values for the 40–49 year group were 0·51 and 0·48 l respectively for the British and US miners, while the over 50 year group values were 0·56 l in both studies. The pattern of changes over the four smoking groups was also broadly similar.

As in the study of Love and Miller,[1] age, height, smoking status, and mine effects all showed significant associations with change in FEV_1. Age related decline was three times greater than in the British study, and showed greater statistical significance, though the relationship of FEV_1 decline to height was similar in the two studies.

The models in the present investigation accounted for 12% of the total variability, somewhat greater than the R^2 of 6% of Love and Miller. The reason for this probably lies with the mine effect term, which, because of the inclusion of more mines in the US study, had more degrees of freedom. Dropping the mine effect term in the present analysis reduced R^2 to 6%. Love and Miller have discussed reasons for these low R^2 values and noted that they are typical in longitudinal studies of lung function.

Though both the British and the current study detected relationships between dust exposure indices and FEV_1 changes, it is difficult to compare the coefficients as these indices were dissimilar in nature. The British investigation included comprehensive information on dust exposure, derived from measurement both before and during the inter-

Table 5 *Predicted average effects of dust exposure and smoking on 11 year adjusted decline in FEV_1 (results from table 4, expressed in litres decline*

Model I	
Decline associated with 11 years' work underground	0·036
Decline associated with smoking*	0·095
Ratio	2·6
Model II	
Decline assoicated with 11 years' work at the face	0·080
Decline associated with smoking*	0·096
Ratio	1·2
Model III	
Decline associated with exposure to 2 mg/m³ coal dust	0·056
Decline associated with smoking	0·093
Ratio	1·7
Model IV	
Decline associated with 35 years, work underground before 11 years	0·084
Decline associated with smoking*	0·096
Ratio	1·1

*Comparison between current and non-smokers.

survey period. In contrast, the only data available in this study were intersurvey compliance concentrations that were not primarily collected for epidemiological investigation. In addition, extrapolation of these data to the period before the first survey is not justified as there is evidence of a substantial change in general dust conditions around 1970, when the Mine Safety and Health Act came into force.

Despite these differences, the basic similarity between the two studies allows comparison of the estimated effects of dust exposure. Love and Miller state that 245 gh/m³ (which corresponds to a lifetime's exposure to coal dust at current British regulatory levels) is associated with a subsequent 11 year average excess decline of 0·087 l. This exposure of 245 gh/m³ corresponds to 35 years' work at a mean concentration close to 4 mg/m³ (Love, personal communication). In the present study 35 years of underground work was found to be associated with an excess decline of 0·084 l (model IV, table 5); but without information on the general dust level before the initial National Coal Study survey we cannot establish complete correspondence. Fortunately, some data on dust levels in US mines before 1969 do exist,[3] and suggest a general dust level of around 4 mg/m³. It is apparent therefore that the two studies agree well on the effect associated with dust.

Comparison of the relative effects of dust exposure and smoking can be made from the results of both studies, although care should be exercised as the magnitude of smoking: dust exposure ratios depends critically on the levels of dust and smoking. Love and Miller state that "the magnitude of the predicted effect of the average exposure to dust on rate of loss of FEV_1 appeared to be about one-third of the average loss due to smoking." The results presented here are generally consistent with their finding. Changes in dust levels and smoking habits from those of the past may result in different estimates in the future.

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